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SOIL DEFLATION ANALYSES FROM WIND EROSION EVENTS

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Abstract. There are various methods to assess soil erodibility for wind erosion. This paper focuses on aggregate analysis by a laser particle sizer ANALYSETTE 22 (FRITSCH GmbH), made to determine the size distribution of soil particles detached by wind (deflated particles). Ten soil samples, trapped along the same length of the erosion surface (150–155 m) but at different wind speeds, were analysed. The soil was sampled from a flat, smooth area without vegetation cover or soil crust, not affected by the impact of windbreaks or other barriers, from a depth of maximum 2.5 cm. Prior to analysis the samples were prepared according to the relevant specifications. An experiment was also conducted using a device that enables characterisation of the vertical movement of the deflated material. The trapped samples showed no differences in particle size and the proportions of size fractions at different hourly average wind speeds. It was observed that most of particles travelling in saltation mode (size 50–500 μm) – 58–70% – moved vertically up to 26 cm above the soil surface. At greater heights, particles moving in suspension mode (floating in the air; size < 100 μm) accounted for up to 90% of the samples. This result suggests that the boundary between the two modes of the vertical movement of deflated soil particles lies at about 25 cm above the soil surface.

Key words: soil analyses, deflation, wind erosion event

INTRODUCTION

Wind erosion involves various types of processes, such as detachment of soil particles from the soil surface by the mechanical power of the wind (abrasion), transport of the soil particles (deflation), and deposition of the detached loose top soil in another place (accumulation) [Varga et al. 2013].

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Soil texture is determined by the size distribution of mechanical particles with mineral origin that have various shapes and sizes as well as differ in mineralogical and chemical composition. The mineral soil particles of specific size are divided into groups with a unique name of the grain size fraction. Every soil fraction consists of particles with similar dimensions; in addition, some of their basic physical and physico-chemical properties are more or less identical [Fazekašová and Torma 2007, Halaj and Bárek 2009].

Aggregate analysis belongs among the methods of wind erosion intensity estimation. It is employed to determine the content of stable soil aggregates using a set of sieves, and it may be carried out either by dry or wet method [McKenzie et al. 2002]. For purposes of determining the amount of non-eroded particles, the dry method is recommended [Larney 2008].

Prior to aggregate analysis, all the collected soil samples should be air-dried at room temperature. Drying the soil at high temperature (e.g. in the oven) could result in the partial combustion of the organic matter as well as in some irreversible changes in the structure of clay minerals due to dehydration. Such conditions could lead to the creation of very stable aggregate formations even within soils that are unstable under normal conditions. Since the aggregate stability increases with storage time, laboratory analysis should be conducted as soon as possible after soil drying. It is recommended that the soil sample should be stored in a layer about 3 mm thick in a place with good air circulation, and be left to dry out for 24 hours [Kemper and Rosenau 1986].

Chepil [1942, 1952, 1962] described the aggregate analysis done by using a rotary screen. This device, having a set of sieves arranged in a row, not only screens the soil sample, but also simulates the abrasion of soil aggregates that occurs under natural conditions due to wind drift. The availability of a rotating sieve, however, is limited because of its price and manufacturing technique (handmaking; not serial production) [López et al. 2001]. For these reasons, alternative methods of determining the size distribution of each soil particle/aggregate have been sought. Toogood [1978] modified the method of aggregate analysis to enable the determination of dry aggregate stability by flat sieves, respectively their sets. Fryrear et al. [1994] used an equation based on the knowledge of dust, sand, clay, organic matter and calcium carbonate representation in soil to calculate the stability of erodible particles. Lopez et al. [2007] used two analytical methods: a standard rotary screen and a set of sieves placed on an electromagnetic (vibrational) shaker. After comparing the amounts of soil particles retained on the sieves, they suggested using an electromagnetic shaker with a set of sieves as a good alternative to the circuit situ. Therefore, to determine the representation of non-erodible particles, they passed 100–200 g of soil sample through a sieve of 0.8 mm mesh size for 5 minutes with the vibration amplitude set at 0.1 mm [López et al. 2001].

The aim of the paper was to determine the particle size distribution of deflated soil samples by aggregate analysis using a laser particle sizer.

MATERIALS AND METHODS

Materials

Soil samples were taken from a flat, smooth area without vegetation cover and without soil crust, where windbreaks or other barriers did not have an impact. The sampling was done from the surface layer of the soil to a depth of maximum 2.5 cm.

Prior to analysis, the soil samples were prepared according to the procedure described hereinafter.

Design of a laser particle sizer

A laser particle sizer ANALYSETTE 22 MicroTec plus (FRITSCH GmbH, Idar--Oberstein) consists of a dry dispersion unit, a measuring unit and a wet dispersion unit (Fig. 1). Selected technical parameters of the measuring and dispersion units are shown in Table 1. Dry dispersion is especially suited for not too fine, free-flowing materials that react in water or other liquids. This type of dispersion is the best suited for measuring the agglomerates of dry powders or for determining the particle size distributions of free--flowing, coarse-grained materials. For soil samples, wet dispersion is an ideal method of dispersion as the samples are fed into a closed liquid circulation system. An integrated and freely programmable ultrasonic emitter ensures fast and extremely efficient degradation of the agglomerates, precisely adapted to each sample. Due to an integrated water connection, the unit can be automatically cleaned and refilled with new, clean liquid after each measurement.

Fig. 1. ANALYSETTE 22 MicroTec plus (left to right): dry dispersion unit, measuring unit, wet dispersion unit (Photo E. Kondrlová)

Table 1. Technical parameters of ANALYSETTE 22 MicroTec plus (FRITSCH GmbH) [Kondrlová et al. 2013, www.fritsch-sizing.com]

Unit	Technical parameters
Measuring unit	Measuring range: 0.08–2000 µm (wet dispersion); 0.1–2000 µm (dry dispersion) Two semiconductor lasers: green (λ = 532 nm, 7 mW); IR (λ = 940 nm, 9 mW) Number of particle size classes: max 108 Optical arrangement: Inverse Fourier design; movable measuring cell (FRITSCH patent) Fourier lenses: 260 mm and 560 mm focal length (green or infrared); 10 mm diameter of the laser beam in the Fourier lens Automatic laser beam alignment Sensor: 2 segments, 1× for vertical and 1× for horizontal direction of the laser light polarisation; 57 elements Typical measuring time: 5–10 s (measurement value recording of a single measurement); 2 min (entire measuring cycle)
Wet dispersion unit	Suspension volume: 300–500 cm^3 Radial pump with adjustable speed Ultrasonic with adjustable output (max 60 Watt)
Dry dispersion unit	Sample volume: < 1–100 cm^3 High frequency feeder Annular gap Venturi nozzle Required compressed air supply: min 5 bar, 125 l/min; oil-, water-, particle-free External exhaust system required

Control software

The analyser is controlled by instructions from the MaS control software that is based on a relational database in which all user entries, parameters and results are securely stored and are safe from manipulation. The software contains predefined Standard Operating Procedures (SOPs) that regulate many typical measurement processes. Own SOPs can be completely freely defined, or the existing ones can be modified to perfectly suit measurement requirements: the dispersion process and duration, measuring frequency, time intervals and many other parameters can be easily selected and saved as separate SOPs. The report generator allows measurement reports to be organised exactly according to the user needs. The user-friendly software interface enables clear organisation of the measuring data; fast comparison of different measurements; freely selectable user values issued in a table format; data export to Excel, PDF, etc.; and storage in SQL databases.

Soil sample preparation method

To prepare a soil sample, 3 g of fine soil (less than 2 mm in diameter) was mixed with 3 ml of Graham's salt and dispersed for 24 hours. Prior to measurement, each sample was mixed well. The sample in the form of suspension was poured into a graduated cylinder and shaken several times.

The measurements were carried out over the whole measuring range of the instrument (0.08–2000 µm) using the Fraunhofer diffraction theory and automatic calculation mode. In cases when the optimal dose (10–15% of beam obstruction) got overloaded, the sample was diluted to the optimal concentration using a software tool. The pump unit (set to level 6) supplied a smooth flow of dispersion liquid and dispersed the sample in an ultrasonic bath and in the measuring cell. Each sample was dosed 3 times and each dose was analysed 3 times, then the mean value ($n = 9$) was calculated. After each sampling, the suspension was discharged from the dispersion unit into a drain, and the unit for wet dispersion was cleaned automatically to get ready for the next measurement.

RESULTS AND DISCUSSION

Distribution of particle sizes

The trapped soil samples ($n = 10$) – products of wind erosion – were analysed for the same length of the erosion surface (150–155 m) but at different wind speeds. The results of this analysis are presented in Table 2.

Table 2. Results of aggregate analysis for samples trapped at various wind speeds

Soil particle size (µm)	% content of aggregates in sample									
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
< 10	20.5	19.9	25.0	26.6	24.0	21.8	25.0	22.2	26.8	23.3
< 50	25.6	25.8	32.9	34.5	31.1	27.9	32.2	28.5	35.0	30.0
< 100	35.7	35.1	41.5	42.7	38.4	36.9	41.3	37.6	45.4	38.1
< 200	67.0	66.6	70.2	70.2	65.6	67.2	70.5	68.0	75.6	66.7
< 500	99.3	99.5	99.5	99.4	99.0	99.4	99.5	99.5	99.8	99.2

V1 – sample trapped at wind speed 6.0 m · s^{-1} V6 – sample trapped at wind speed 8.1 m · s^{-1}
V2 – sample trapped at wind speed 7.0 m · s^{-1} V7 – sample trapped at wind speed 8.2 m · s^{-1}
V3 – sample trapped at wind speed 7.2 m · s^{-1} V8 – sample trapped at wind speed 8.8 m · s^{-1}
V4 – sample trapped at wind speed 7.5 m · s^{-1} V9 – sample trapped at wind speed 8.9 m · s^{-1}
V5 – sample trapped at wind speed 7.6 m · s^{-1} V10 – sample trapped at wind speed 9.1 m · s^{-1}

The trapped samples displayed no differences in particle sizes and their percentage distribution at the different hourly average wind speeds. Although the average speed for trapping sample V1 was 6.0 m · s^{-1}, the wind erosion occurred in gusts of wind speed from 9 to 10 m · s^{-1} and higher. These results showed that the movement of particles was in all cases caused by the wind with about the same speed but with different durations. For this reason the distributions of soil particle fractions were relatively similar in all samples.

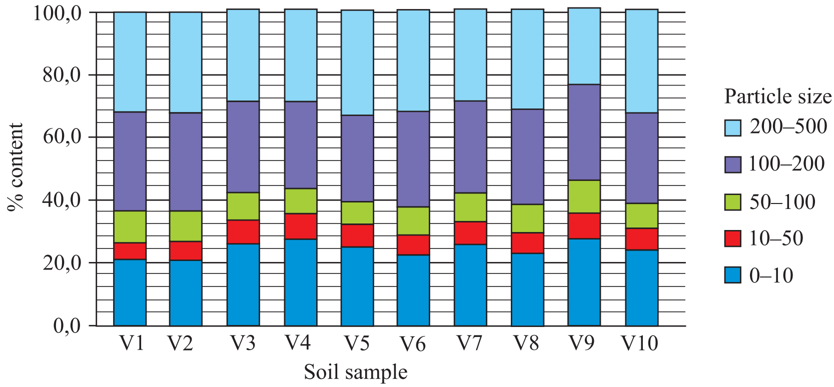

Fig. 2. Results of aggregate analysis for samples trapped at various wind speeds

Vertical movement of deflated particles

The maximum movement of soil particles was observed very close to the soil surface and was due to saltation. With increasing height, the percentage of particles moving in saltation mode decreased and at a certain height only the finest particles remained suspended in the air. To characterise the vertical movement of the deflated soil particles, measurement was performed using a device composed of six individual devices, placed one above each other (with 2 cm gaps; Fig. 3). In this way, the vertical movement from the soil surface up to 40 cm was captured.

Fig. 3. Arrangement of the device used for vertical measurement

The movement of soil particles through the gaps was estimated by interpolation. The total transport of soil up to 40 cm height, therefore, increased from 646.7 to 792.1 g. Considering this amount as 100% transport (not taking any transport above 40 cm height into account), we found that 71% of the soil particles was transported within the first 5 cm above the soil surface, and 97% of the total transport occurred between 0 and 15 cm.

Table 3. Results of aggregate analysis for samples D4-0 and D4-5

Soil particle size (µm)	% content of aggregates in sample					
	D4-0	D4-1	D4-2	D4-3	D4-4	D4-5
< 10	22.7	22.7	25.2	27.1	40.0	45.1
< 50	35.7	29.4	36.3	42.2	70.4	73.5
< 100	43.9	36.9	45.4	54.9	89.4	91.1
< 200	71.6	64.3	69.1	77.7	99.6	99.8
< 500	99.5	98.9	98.4	99.2	100	100

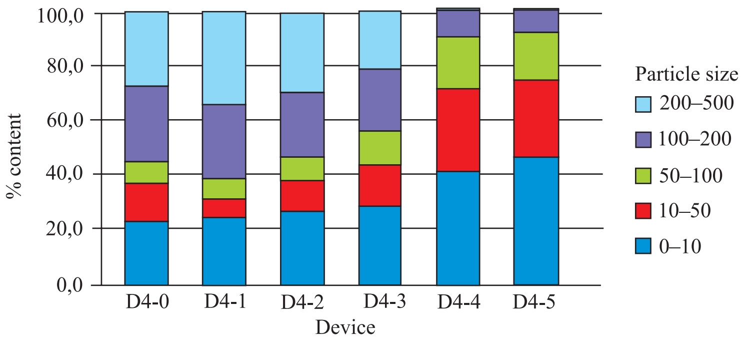

Fig. 4. Results of aggregate analysis for samples trapped at various heights

Further analysis revealed that the particles travelling in saltation mode (particles 50–500 µm) moved vertically mainly up to 26 cm above the soil surface (58–70%). The latter fraction was considerably less represented in the upper height ranges (higher than 26 cm above surface); its proportion there reached 28%. The particles moving in suspension mode (particles < 100 µm) accounted for approximately 90% of samples D4-4 and D4-5. This result indicated that the boundary between particles moving in saltation mode and those floating in the air was at about 25 cm above the soil surface. As shown by observations of the soil particle transport in suspension mode, increasing the surface length increases the amount of the earth's crust movement. The transport of particles in suspension mode was observed up to 2.5 to 3 m above the surface. When encountering permanent barriers, such particles can be dispersed to greater heights and thus transported to longer distances, often to residential zones and urban settlements.

CONCLUSION

The movement of soil particles is caused by wind forces affecting the stability of the soil surface. The average wind speed increases exponentially with height above the soil surface. In this study we performed an aggregate analysis of eroded soil to determine the size distribution of the eroded soil particles as dependent on wind speed and height of its occurrence. Analyses of soil samples trapped under various wind conditions showed no difference in particle size distribution at different hourly average wind speeds. By contrast, analysing samples from vertical arrangement of devices D, we found that particles travelling in saltation mode (particles 50–500 μm) moved vertically mostly up to 26 cm above the soil surface. The movement of particles in suspension mode (particles < 100 μm) accounted for approximately 90% of samples D4-4 and D4-5. We concluded that the boundary between particles moving in saltation mode and those travelling in suspension mode (floating in the air) is at about 25 cm above the soil surface.

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ANALIZY DEFLACJI GLEBY SPOWODOWANEJ PRZYPADKAMI EROZJI WIATROWEJ

Streszczenie. Istnieje wiele metod oceny erozyjności gleby poddanej działaniu wiatru. Niniejsza praca dotyczy analizy wykonanej za pomocą analizatora laserowego ANALYSETTE 22 (FRITSCH GmbH) w celu określenia rozkładu granulometrycznego cząstek glebowych wywiewanych przez wiatr (ulegających deflacji). Analizie poddano 10 próbek gleby uzyskanych na powierzchni erozyjnej o takiej samej długości (150––155 m), lecz przy różnej prędkości wiatru. Próbki gleby pobierano z głębokości do 2,5 cm, z płaskiej, gładkiej powierzchni bez roślinności i bez warstwy twardej skorupy ziemskiej, gdzie nie występował wpływ wiatrochronów czy innych barier. Przed analizą próbki odpowiednio przygotowywano. Przeprowadzono również doświadczenie przy użyciu urządzenia pozwalającego na scharakteryzowanie pionowego ruchu wywiewanych cząstek. Stwierdzono, że badane próbki nie różniły się wielkością cząstek ani udziałem poszczególnych frakcji rozmiarowych przy różnej średniej godzinowej prędkości wiatru. Zaobserwowano, że większość (58–70%) cząstek przemieszczających się w trybie saltacji (cząstki o średnicy 50–500 μm) porusza się pionowo do wysokości 26 cm nad powierzchnią gleby. Na większej wysokości, cząstki poruszające się w trybie zawieszenia (cząstki unoszące się w powietrzu; o średnicy < 100 μm) stanowiły do 90% cząstek próbki. Ten wynik sugeruje, że granica między tymi dwoma trybami pionowego ruchu wywiewanych cząstek znajduje się na poziomie około 25 cm nad powierzchnią gleby.

Słowa kluczowe: analiza gleby, deflacja, przypadek erozji wiatrowej

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